Good Practice

Guide 3

Introduction to Small - Scale Combined Heat and Power

BEST PRACTICE PROGRAMME
ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

INTRODUCTION TO SMALL-SCALE COMBINED HEAT AND POWER

This booklet is No. 3 in the Good Practice Guide Series and provides an introduction to the technology and application of small-scale packaged combined heat and power (CHP) units. It is designed to give guidance to potential users and their technical advisers (consultants, architects and building services engineers). Particular emphasis is placed on the use of CHP systems to reduce energy costs in buildings, and application studies of several successful CHP installations are included. Details of finance options are also given, covering outright purchase as well as packages covering supply and installation at no cost, paid for out of savings.

More detailed technical information is available in the separate publication, Good Practice Guide 1 'Guidance Notes for the Implementation of Small-scale Packaged Combined Heat and Power' and Good Practice Guide 60 'The Application of Combined Heat and Power in the UK Health Service'.

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First published 1985 as Energy Technology Series 4
Reprinted 3/96

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FOREWORD

This guide is part of a series produced by the Department of the Environment under the Energy Efficiency Best Practice programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

— *energy consumption guides:* (blue) energy consumption data to enable users to establish their relative energy efficiency performance;

— *good practice guides and case studies:* (red) independent information on proven energy saving measures and techniques and what they are achieving;

— *new practice projects:* (green) independent monitoring of new energy efficiency measures which do not yet enjoy a wide market;

— *future practice R&D support:* (purple) help to develop tomorrow's energy efficiency good practice measures.

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1. INTRODUCTION

Virtually all electrical power is produced by a generator driven by some form of heat engine, such as a steam or gas turbine in a large power station or an internal combustion engine in a generating set. However, only a proportion of the energy supplied to such engines is converted into shaft power; the remainder is usually rejected to the environment as waste heat.

In conventional electricity generating plant approximately 65% of the initial primary energy input is rejected. Most of this is in the form of water at a temperature of 30 - 35°C, which can rarely be used economically.

It is possible to design generating systems which recover the majority of the reject heat for productive use. Such 'Combined Heat and Power' (CHP) generation systems make the reject heat available at a higher temperature, so that it is suitable for space heating in buildings or for process uses in industry. Typically an overall efficiency of 80% is achievable with CHP.

1.1 Small-scale CHP

Small-scale CHP usually refers to units with electrical outputs of up to 1 MWe (CHP plant is generally sized by reference to the electrical output). Nearly all such units are available from suppliers as complete standard packages, assembled and tested before delivery to site. Typically a small-scale CHP unit converts about 30% of the input energy to electricity and 50% to useful heat. The thermal (heat) output of this type of unit is therefore around 1.7 times the electrical rating.

Small-scale CHP is now a well-established technology and properly designed installations achieve payback periods of typically between 3 and 5 years. Over 900 sites in the UK now have small-scale CHP installed with a total capacity of around 120 MWe (1994) and this is still growing. Fig 1 shows a typical small-scale CHP installation.

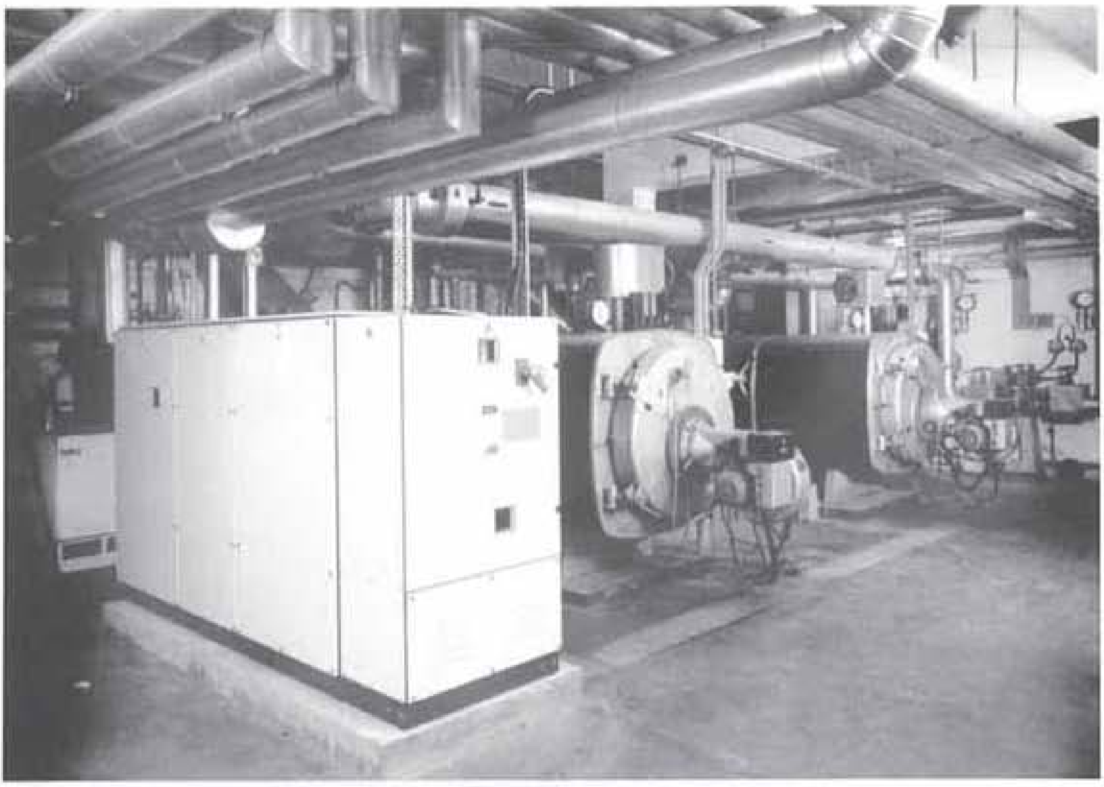

Fig 1 A typical small-scale gas-fired CHP installation
The CHP unit in the foreground provides base load heat and electrical power and additional heat is provided by the boilers.

There are several reasons for the uptake of small-scale CHP systems:

- the development of standard packaged units;
- rising energy costs have made both suppliers and potential users aware of the financial benefits that these systems can provide by reducing energy costs;
- the use of CHP yields environmental benefits, including lower carbon dioxide and sulphur dioxide emissions, due to the high efficiency of CHP and the use of the relatively clean fuel, natural gas;
- suppliers of packaged CHP plant offer a variety of 'no capital cost' financing options in addition to outright capital purchase;
- the Government has recognised the energy efficiency and environmental benefits of CHP systems, and has encouraged their wider use by removing institutional, legislative and market barriers. As part of its Climate Change Programme, the Secretary of State for the Environment has set a target of 5,000 MWe of CHP capacity to be installed in the UK by the year 2000.

The compact size of small-scale CHP units, together with their heat and electrical output, makes them suitable for use in a range of different building types, such as hotels, hospitals, universities, residential homes and leisure centres. Sewage treatment works and other sources of biogas can be suitable for small-scale CHP and also there are many industrial sites where the technology is applicable. Furthermore, some units can provide standby power generation capacity; they operate linked to the grid for most of the time, but can also operate independently to meet essential electrical loads in the event of mains failure.

The purpose of this document is to introduce the use of small-scale CHP systems as a cost-effective method of improving energy efficiency in a variety of building types. Good Practice Guide 1 contains more detailed information relating to the specification and the financial and operating implications of CHP.

2. SMALL-SCALE CHP: THE TECHNOLOGY

2.1 How Savings are Achieved

Small-scale CHP units make use of a single, relatively low-cost fuel, usually natural gas, to generate both heat that a conventional boiler would otherwise produce using the same fuel, and electricity that would otherwise be purchased from a Regional Electricity Company (REC) at a relatively high cost. Although generally the units are slightly less efficient than boilers as heat generators, direct savings in electricity unit costs and, often, maximum demand charges more than offset this.

A CHP installation will be most cost-effective when it operates for the maximum number of hours during those periods when heat is required and when electricity tariffs are favourable. To achieve an acceptable payback period in the range 3 to 5 years, the CHP unit generally must operate for at least 4,500 of the 8,760 hours in a year. In practice, most potential applications have fluctuating demands for both heat and electricity throughout the year, so if a CHP system is sized to meet the peak demands it will inevitably be under-utilised for most of the time. Generally the most cost-effective systems will be sized to meet the site base heating or electrical load, with the peaks being met by supplementary boilers and by purchasing electricity from the grid.

2.2 System Components

The main components of a small-scale CHP system are shown in Fig 2. These include:

- **an engine**, which drives an electricity generator;
- **a generator**, which produces the electricity;
- **a heat recovery system**, to recover the waste heat from the engine;
- **a control system**, to ensure safe and efficient operation of the installation;
- **an exhaust system**, to carry away the products of combustion;
- **an acoustic enclosure**, to prevent excess noise and provide weather protection to the unit or physical protection to the operators.

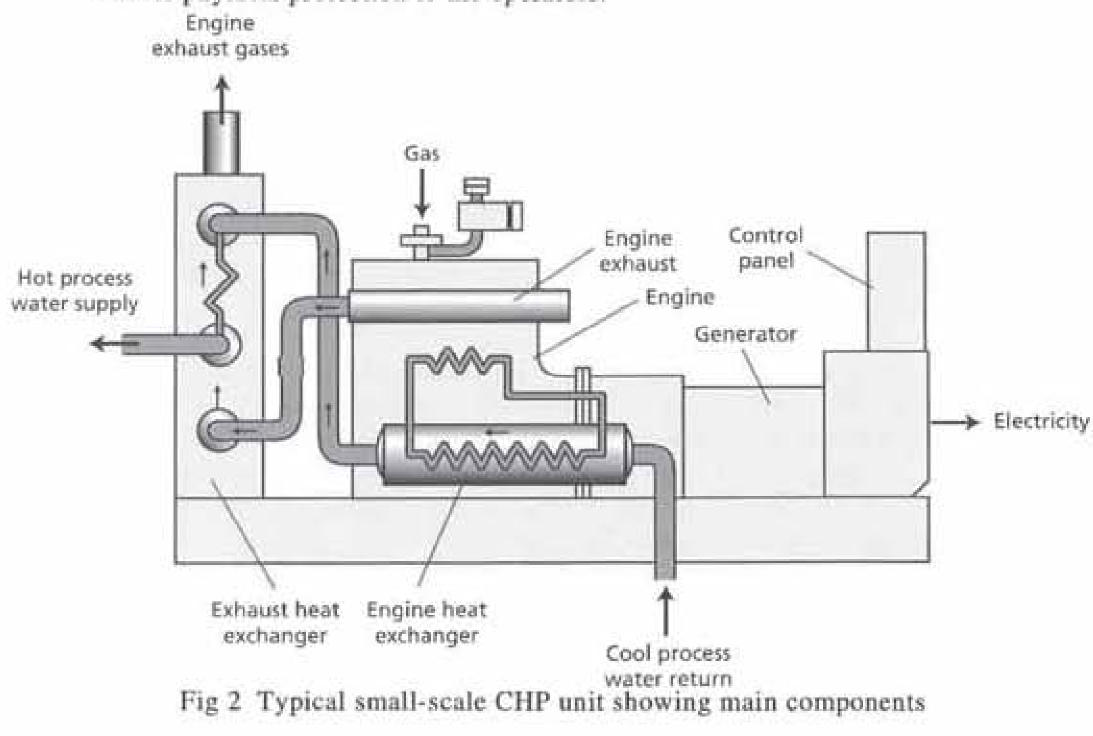

Fig 2 Typical small-scale CHP unit showing main components

The systems are called 'packaged' units because, with the exception of the engine exhaust, the main components are usually combined in a single module. They are delivered as a prefabricated unit, ready for connection to the various services.

2.3 Engines and Maintenance Requirements

The engines can be of various types including spark ignition, running on natural gas or biogas; or diesel cycle, running on oil. They can also be either industrial engines or engines derived from mass-produced automotive units. Industrial engines are generally used in packages with electrical outputs above 150 - 200 kWe.

It is important to ensure that the assessment of the CHP savings includes realistic life-cycle maintenance costs. These include parts and labour requirements for lubrication services, top end and full overhauls. However, the CHP savings support these costs so that typical paybacks are within the range 3 to 5 years.

2.4 Fuels

In principle, a CHP unit can run on any fuel that will drive a suitable engine. In practice most systems run on either natural gas or biogas. Small-scale CHP units that run on diesel fuel or gas-oil are available. However, due to the high cost of the fuel, it is unlikely that such units will be cost-effective, except in special cases, such as where gas-oil is already used on site and there is no gas supply available. The effect of the increased maintenance costs compared with natural gas engines needs careful assessment. Dual fuel engines, where diesel is used for starting and ignition purposes and gas for running, are generally not available for units of output less than 500 kWe.

The fuel for a particular application will be selected mainly on the basis of availability and price. It is preferable to use the fuel which is cheapest in terms of cost per unit of output from the CHP unit. The unit cost of the fuel for the CHP unit should be similar to that of the main boiler plant; this could otherwise substantially offset savings in purchased electricity.

The first choice of fuel for most applications will usually be natural gas, where this is possible. Natural gas is widely available, and the equipment manufacturers have devoted considerable efforts to developing efficient gas-fuelled CHP units.

Sewage treatment plants can often operate CHP units on biogas. Although the cost of this fuel is low - it may even be a 'free' by-product - biogas has a relatively low and variable calorific value, and therefore the power output of the engine and generator will be reduced. In addition, consideration must be given to contaminants, such as sulphur, which may be present in the biogas. Nevertheless, if this fuel is available it should be seriously considered.

In contrast, liquefied petroleum gas (LPG) is more expensive than natural gas. It is unlikely to be cost-effective for most applications, and the cost of tank storage is relatively high. However, it may be suitable in some circumstances, for example where natural gas is not available but where LPG is already in use for other purposes.

The use of gas-oil will generally depend on the availability of an existing fuel supply system and the relative price of natural gas. Increased electrical generation efficiency is an advantage of high-compression diesel engines and, in addition, they have a lower heat-to-power ratio when compared with a natural gas spark-ignition engine. Maintenance costs should take account of the more complex fuel injection system, the need for more frequent oil changes and the increased heat exchanger cleaning required due to soot formation.

2.5 Engine Performance

The overall efficiency of fuel conversion in a CHP unit is typically around 80% (Fig 3). Approximately 30% of the fuel energy is delivered as mechanical work to drive the electricity generator, where the conversion into high-value electricity occurs with only small losses. In contrast to more conventional generator systems, small-scale CHP units recover a substantial proportion of the remaining 70% of the energy available from the fuel in the form of hot water.

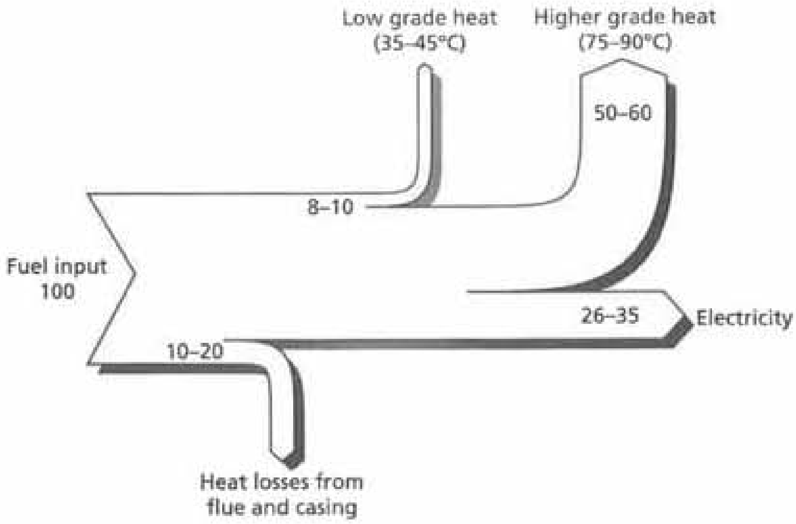

Fig 3 Energy balance of a typical CHP unit

2.6 The Generator

The generators used in packaged CHP units have 3-phase alternating current outputs at 415 V. Most modern units are synchronous rather than asynchronous.

A **synchronous generator** can operate in isolation from other generating plant and the grid. The voltage and frequency are determined solely by the control equipment of the unit. The speed of rotation of the rotor determines the frequency, and remains constant as the power demand of the load varies.

A synchronous generator can continue to supply power during mains failure, and so can act as a standby generator. Since this type of unit starts from batteries, it does not affect the grid voltage on start-up.

A **mains-excited asynchronous generator** can only operate in parallel with other generators (such as the grid), since reactive power from the grid supplies its magnetic excitation. The grid determines the voltage and frequency of the unit, and the unit itself will therefore stop if it is disconnected or if the mains fails. The output frequency is thus automatically matched to the mains, and connection and interfacing to the grid is simple. CHP packages with asynchronous generators can be provided for smaller systems (up to about 100 kWe).

There are two principal ways of operating a small-scale CHP system:

- **parallel operation**, in which the CHP unit generates electricity to meet the general electrical load, but is supplemented by the grid if demand is greater than the system output. Conversely, if the load is smaller than the output, power can be exported to the grid or the output modulated;

- **standby operation**, where the unit supplies part of the total load if there is a failure of the grid. The maximum demand put on the unit must be controlled to protect it from overload.

Synchronous generators are usable in both modes of operation, whereas the mains-excited asynchronous generator cannot provide standby power in the event of a grid failure.

2.7 The Heat Recovery System

All small-scale CHP units recover heat from the engine coolant and the exhaust by using heat exchangers. In this way 80 - 85% of the heat rejected by the engine can be recovered. This can be increased to 90% or more if the latent heat in the exhaust gases is recovered by using a condensing heat exchanger. However, incorporating additional heat exchangers will raise the cost of the unit, and their inclusion will not always be justified. While all small-scale CHP units incorporate a condensate drain in the exhaust, this may need enlarging if a condensing economiser is fitted.

Generally heat recovery is via a fully closed system with an interfacing plate heat exchanger linked to the boiler water circuit. This avoids problems with fouling, scaling and air locks within the exhaust and engine coolant heat exchangers.

Typical heat outputs for small-scale CHP units range from around 60 kW up to 1,600 kW and are typically 1.7 times the nominal electricity output. The maximum operating water temperatures and pressures at which CHP units can be used depend upon manufacturers' specifications, but are generally similar to those for other low temperature hot water (LTHW) services at approximately 75 - 90°C and 3 - 7 bar. In addition, low grade heat as hot water at up to 45°C and warm air can also be recovered if necessary. Larger units of 250 kWe upwards can generally be integrated into MTHW systems.

2.8 The Controls

For a CHP system to operate satisfactorily, the design of the control system must accommodate the following priorities:

- safety;

- reliability;

- ease of plant operation;

- efficiency.

Control systems are typically microprocessor-based, including, or with the option of, remote communication facilities.

Integral controls ensure that all CHP units operate both within their margins of safety (temperature, pressure and emissions) and within the limits required by the Regional Electricity Company. The Electricity Association's Engineering Recommendation G59/1 and Engineering Technical Report ETR113 specify the detailed electrical and safety requirements that the private generator must meet. The Regional Electricity Company will verify compliance with these requirements before connection to the supply is permitted.

However, from the user's point of view, control often means the method by which the operator determines the use of the plant. In this sense, a CHP unit may respond to heat demand, with or without regard to electricity requirements, or alternatively, it may respond to electricity requirements, with due regard to site heat requirements.

In practice CHP units are normally activated by a requirement for heat, i.e. when the temperature in the hot water circuit falls below a set point, and the electricity generated primarily meets the user's own requirements. The control requirements of CHP units operating in this mode are similar to those of a conventional boiler installation. However, if CHP units operate in conjunction with conventional boilers, it is essential for the CHP units to have priority since the commercial viability of the system depends on its operation over the maximum period possible (normally in excess of 14 hours per day).

Synchronous units can be controlled in relation to variations in the electrical load. For example, it is possible to operate a 75 kWe unit successfully over the range 37 - 75 kWe, with a similar proportional variation in heat production. No electricity is exported, and conventional boilers supply the remaining heat. If the unit is to be cost-effective, modulation of electricity output in this way should only be used for a few hours each day, with the majority of operation at full load.

With small-scale CHP there is generally no export of electricity since the value of exported power typically only just covers the cost of fuel and maintenance. It is usually more cost-effective to design a smaller system to use all the generated heat and electricity on site rather than to export electricity.

2.9 The Acoustic Enclosure

CHP units are usually enclosed to reduce the noise levels to approximately 65 - 75 dBA rating at 1 metre. While these levels are below those encountered with forced draught boilers, they are higher than typical levels for atmospheric boilers. As a result, additional acoustic treatment may be necessary if noise is likely to be a problem (e.g. if units operate at night in quiet residential areas).

The noise problem most commonly encountered with reciprocating engine based CHP is that of low frequency vibration, and consequently anti-vibration mountings and couplings are usually fitted to packaged CHP units as standard.

3. TYPICAL APPLICATIONS FOR SMALL-SCALE CHP

The first small-scale CHP units installed in the UK were in hotels, swimming pools and sewage treatment works. The first two areas have a large and consistent demand for both heat and electricity, while the latter can take advantage of a cheap fuel - sewage gas - generated on site.

In all CHP applications, it is essential that the characteristics and performance of the installed system match the site load requirements. This will maximise the load factor and thus ensure cost-effectiveness.

One approach is to view a CHP unit as a direct replacement for a normal gas boiler, but with the added advantage of electricity production. The key characteristic of a CHP system is that it provides both heat and electrical power in the ratio of approximately 1.7 to 1. Approximately 50 - 60% of the energy input is available as heat, and 25 - 30% as electricity, so overall energy conversion (input energy to heat and electrical power output) is about 80%, and sometimes as high as 90%. This compares favourably with a normal small gas boiler of up to 100 kW load, with a seasonal efficiency of 65 - 75%.

While a CHP system costs substantially more to install, fuel and maintain than a gas boiler, the procedure for interfacing a unit to conventional plant is relatively straightforward. It is important to consider simple no-cost and low-cost energy efficiency measures first since these will affect the choice of CHP plant. The economic viability of an installation depends on whether the value of the generated electricity can repay the extra capital costs within a reasonable time. Furthermore, CHP should always be assessed against other competing options, such as improved boiler controls or a more efficient heating system using high efficiency or condensing boilers. It is essential to identify and implement simple, low-cost efficiency measures, as they will affect the sizing of the CHP system. Good Practice Guide 1 and Good Practice Guide 69 'Investment Appraisal for Industrial Energy Efficiency' contain details of cost-benefit appraisal techniques.

Experience has shown that, with current fuel tariffs and allowing for the extra installation and life-cycle maintenance costs, commercial payback periods of 3 to 5 years are achievable if the following criteria are satisfied:

- a sufficiently large heat load exists over a substantial proportion of the year, to enable the unit to run for at least 14 hours each day;
- the electrical load remains above the output of the unit for most of the expected operating hours;
- the heat and electrical loads are simultaneous;
- a suitable location exists for the unit (typically in a boiler house) with accessible services (gas, electricity and heating) to reduce installation costs. Prefabricated outside enclosures can be provided if there is insufficient space elsewhere, but this will incur an additional cost.

These criteria for the economic operation of CHP mean that sites have to be carefully investigated to assess the heating and electricity demand profiles in order to size the CHP system accurately. This feasibility study should happen in stages as the final decision will involve obtaining detailed information and, unless the initial findings are encouraging, the effort entailed may not be warranted. Good Practice Guide 1 fully describes the sizing of a CHP system and the methodology of feasibility studies.

Typical applications where CHP has been successfully installed include:

- hotels;
- swimming pools and leisure centres;
- hospitals;
- grouped accommodation, prisons and detention centres;
- educational establishments;
- mixed use applications, such as police headquarters;
- industrial processes;
- sewage treatment plants.

A series of case studies on particular installations published by the EEO provide more detailed information. A list of EEO CHP publications is available from the Energy Efficiency Enquiries Bureau, ETSU, Harwell, Oxon OX11 0RA. Tel No: 01235 436747. Fax No: 01235 433066.

3.1 Hotels

Medium-to-large hotels with over 50 bedrooms need space-heating for up to 18 hours per day extending over a long heating season, together with a large hot water demand for residential and catering needs. Electricity demand tends to be fairly constant throughout the year, again for up to 18 hours per day. In many hotels demand can be reduced during mid-morning and afternoon periods. It is therefore important to investigate carefully the electricity and heat demand profiles to size the CHP unit correctly for cost-effective operation. In smaller hotels with fewer than 50 bedrooms, heat demand can be low during the summer months.

Swimming pools and leisure facilities enhance the viability of CHP and can make a scheme cost-effective where it otherwise would not have been. Where necessary, additional exhaust silencing, installation of flexible couplings to pipework and extra acoustic cladding of the packaged unit or the plant room itself can reduce noise levels. However, in practice noise has not been a serious problem. There are already many hotels with small-scale CHP in the UK, and the number is increasing.

The Derwent and the Victoria are two adjacent hotels in Torquay with a combined capacity of 270 bedrooms and a leisure complex and swimming pool (Fig 4). In November 1986 a Cogen Systems 48 kWe CHP unit was installed in the Derwent Hotel. The unit operates in parallel with the grid and only when there is a demand for heat. The output is modulated in accordance with the electrical load and there is no electricity export. A sequence controller was installed in the boiler house so that the CHP acts as the lead heat source. This achieved a payback period of 4.6 years. The hotel management have now installed another 48 kWe unit with a condensing heat exchanger serving an outdoor pool at the Victoria Hotel, which achieved a payback period of about 4 years. An alternative strategy in a large hotel is to install a single CHP unit of higher capacity.

EEO Best Practice programme New Practice Profile and Report 30 contain further details of this installation.

Fig 4 The Victoria and Derwent Hotels, Torquay where two 48 kWe CHP units are installed

3.2 Swimming Pools and Leisure Centres

Swimming pools have a relatively steady demand for energy throughout the year. Heating is necessary for pool water, ventilation air and domestic hot water (for showers, etc.), while the electrical demand for pumps, air handling equipment and lighting is also fairly constant. Under these conditions it is possible for small-scale CHP units to achieve the maximum of 14 operational hours per day required for cost-effectiveness. Using a condensing heat exchanger in the engine exhaust to pre-heat the pool water as it leaves the filter beds will recover additional heat. This allows the system to achieve operating efficiencies of 90% or more. There are around 300 existing installations in the UK and payback periods of 3 to 4 years are typical.

Detailed monitoring of a 35 kWe Combined Power Systems (CPS) Ltd CHP unit at Wilmslow Leisure Centre (Fig 5) has shown that the system saves over £6,000/year giving a payback period of 3.5 years. The CHP system operates as 'lead boiler'. A remote computer monitoring system supplied by the manufacturer means the CHP unit requires no local supervision by staff.

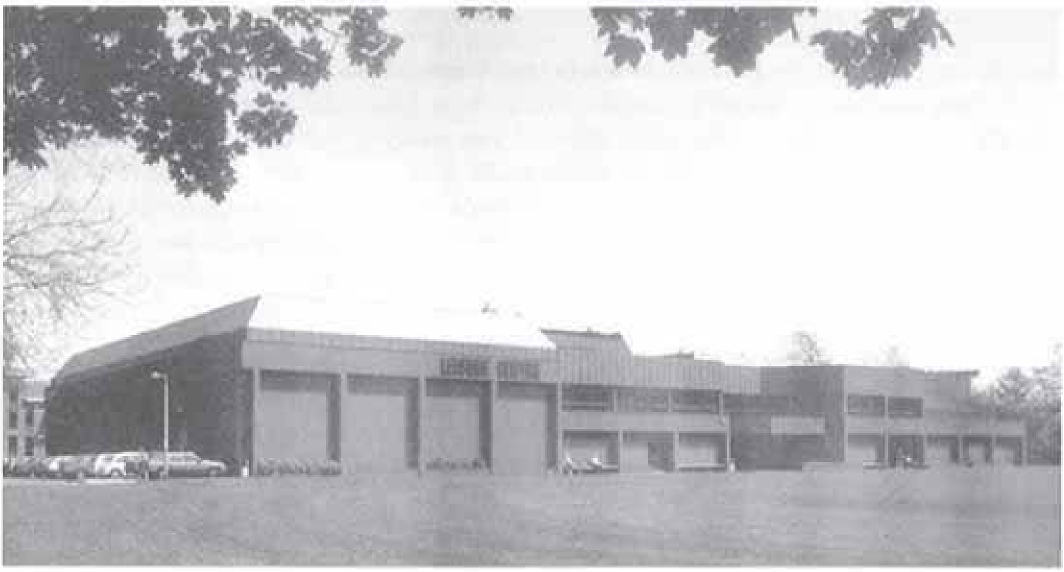

Fig 5 Wilmslow Leisure Centre in Cheshire has heat and power provided by a 35kWe CHP unit

3.3 Hospitals

The space heating requirement in large and small hospitals extends over much of the 24-hour period, and there are substantial hot water and electrical demands for up to 20 hours per day. Small-scale CHP units can therefore operate for long periods with all the heat and electricity generated being used on site. This in turn results in short payback periods. At present there are approximately 150 small-scale CHP units installed in hospitals, and this number is increasing. Large units, including gas turbine installations, may be more appropriate for some sites, particularly large District General Hospitals.

In 1993 a Petbow Cogeneration Ltd 54 kWe CHP unit was installed at the 180-bed Bensham Hospital in Gateshead (Fig 6). The CHP is connected in series with the existing boiler plant via the common return pipework and provides 103 kW of heat, running 17 hours per day. The unit automatically modulates and so compensates for variations in the heat load. The unit runs as the lead heat source and it is likely that only one boiler will need to operate in winter, with hardly any output necessary in summer. The hospital expects a saving of £10,400 per year and a payback of 3 - 4 years.

Fig 6 The-180 bed Bensham Hospital where a 54 kWe CHP is installed

3.4 Grouped Accommodation, Prisons and Detention Centres

Grouped accommodation, such as sheltered housing for elderly, requires relatively high room temperatures for up to 18 hours per day. This high heating demand, coupled with substantial hot water and electricity requirements for 14 - 16 hours per day, is another example where small-scale CHP units can be cost-effective. Attention to noise levels may be necessary if the plant room is adjacent to living quarters, but standard methods for reducing sound can achieve levels below 65 dBA. Residential flats have similar characteristics, and CHP is worth considering if central hot water services exist or are planned.

Early in 1988 Macclesfield Borough Council installed a 35 kWe CPS CHP unit without capital outlay under an Equipment Supplier Finance scheme. The Council uses the Norweb distribution system, under the 'Use of System' tariff, to export surplus electricity to another sheltered housing complex one kilometre away. To control noise levels the unit panels are treated with an acoustic attenuating material and the engine is fitted with an air intake silencer. An important benefit of the unit is that operation is automatic and needs no on-site supervision because the supplier performs remote monitoring.

Fig 7 The Maplewood Sheltered Housing Complex at Macclesfield where a 35 kWe CHP unit serves 60 self-contained flats

3.5 Educational Establishments

Sites such as schools, colleges and university campuses often comprise a mixture of administration buildings, residential accommodation and recreational facilities which are utilised on a year-round basis, both for students, vacation visitors and evening classes. Demand for heating is high and a CHP unit can operate for 15 - 17 hours/day throughout the year. The CHP installation can be operated in parallel with existing LTHW boiler systems and can be coupled to domestic hot water (DHW) or steam heat calorifiers.

The Leith Academy (Fig 8) is a new community school in Edinburgh and as such is open from early morning until late at night, seven days a week,with more than 1,000 people making use of the facilities in addition to the 900 pupils. Early in the planning stages it clear that the school was going to have a large and constant demand for heat and electricity and so a CHP feasibility study was carried out. As a result, a Lincoln Green Energy natural gas-fired 40kWe CHP unit has been installed in conjunction with modern coal-fired boilers. The CHP unit runs for 24 hours a day and should achieve a payback period of around 3 years.

Fig 8 Leith Academy has a 40 kWe CHP installed

3.6 CHP as Standby

Many organisations dependent on electricity have diesel generator sets as an insurance against failure of the mains electricity supply. Where appropriate, the use of CHP plant to provide this standby facility has a number of advantages over conventional generators. If new standby capacity is necessary then the use of CHP avoids the cost of conventional sets. Conventional standby sets are infrequently used and consequently often suffer from poor reliability. With a CHP unit running most of the time there can be more confidence in the reliability of the standby supply.

At West Yorkshire Police the Energy Manager reviewed the existing standby requirements at police premises and found that they were frequently oversized. He assessed what the truly essential loads were and found them to be as little as 25% of the existing generator ratings. The resulting sizes were close to the ideal CHP size ratings for the sites so the two requirements were integrated together. Since 1989, fourteen CHP/standby units from Nedalo and SPP (now Lincoln Green Energy) have been installed in 7 sites, with a policy to install further units throughout the estate.

Fig 9 The West Yorkshire Police HQ, Wakefield where two 85 kWe CHP units are installed

3.7 Industrial Processes

Industrial processes can have high demands for both heat and electricity. Although many industrial processes operate at higher temperatures than a small-scale CHP unit can supply, CHP can provide needed process hot water. Normally the minimum period of operation necessary for a cost-effective small-scale CHP installation will only be achieved with two or three shift operations.

In early 1993 a 750 kWe Cogen Systems CHP unit was installed at Carlsberg-Tetley's Mistley Maltings plant in Essex (Fig 10). The plant converts barley to malt which is the basic feedstock for brewing beer. The 1,120 kW of heat output from the CHP dries the germinated barley via air heater batteries. The unit supplies the site's baseload electricity requirements and provides a standby facility in the event of mains failure. Carlsberg-Tetley expects a saving of around £100,000 per year and a payback of under 4 years.

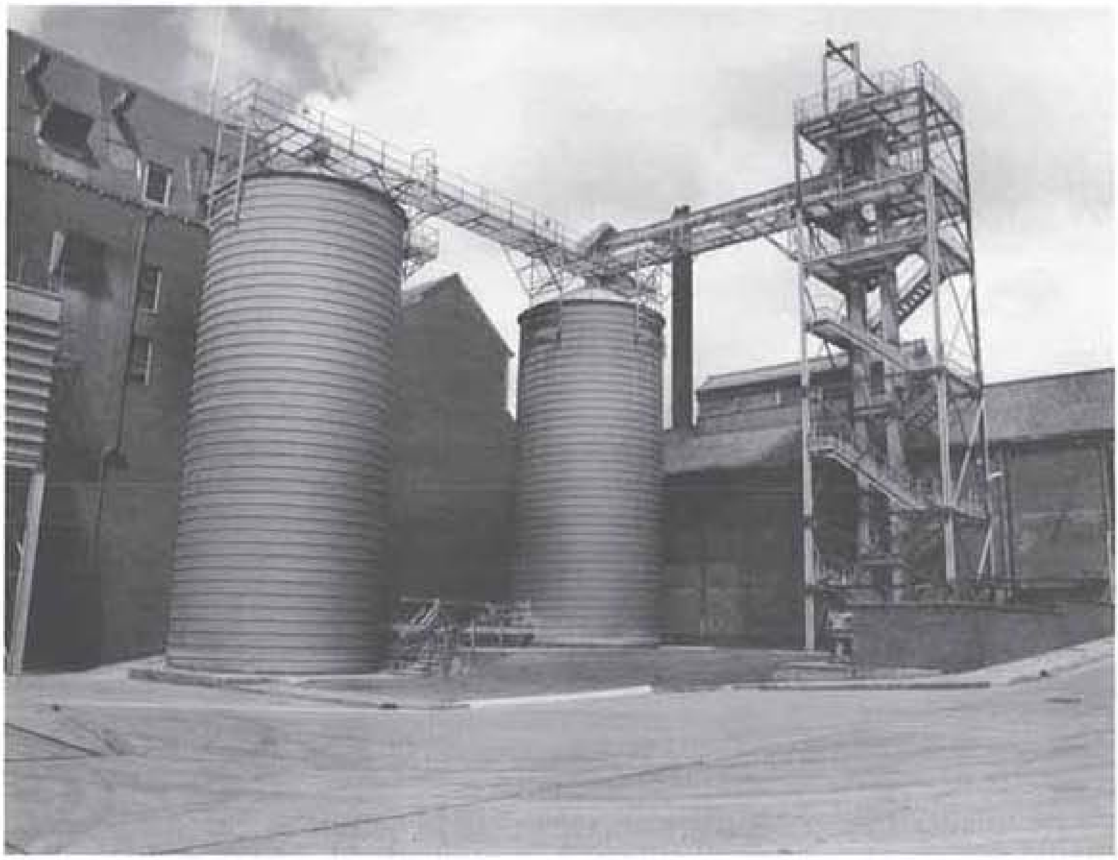

Fig 10 Carlsberg-Tetley's Mistley Maltings where a 750 kWe CHP provides the heat for drying germinated barley via air heater batteries

3.8 Sewage Treatment Plants

Sewage plants have a 24-hour-per-day heat requirement for most of the year for warming digestion tanks. In addition, a continuous electrical demand is necessary for operating pumps. Sewage plants have the added advantage of being able to use as a fuel the biogas produced during the digestion process. As a result, short payback periods in the range 3 - 4 years or less are achievable. More than 100 small-scale CHP units have so far been installed at sewage works. CHP sizes range upwards from 20 kWe for small local sewage treatment works.

When replacement of existing digester-heating boilers became necessary at the Countess Wear works (Fig 11), the cost-effectiveness of CHP was investigated. In 1986 four Nedalo 155 kWe CHP units, capable of operating on biogas, were installed on a three-duty/one-standby basis, thereby producing a maximum output of 465 kWe. All but about 25 kW of the electrical output from the units is exported directly to the grid under a Non-Fossil Fuel Obligation (NFFO) agreement. Recovered heat provides LTHW for the sludge digesters and the heating and hot water requirements of the laboratory, offices and workshop. Gas production determines the operation of the units and the system dumps any heat in excess of site requirements. This installation achieved a payback period of 3.9 years. South West Water have installed further CHP units and have a policy to implement CHP at all suitable sites.

Fig 11 This large sewage treatment works at Exeter has four 155 kWe CHP units operating on digester gas

4. COSTS, BENEFITS AND OTHER IMPLICATIONS

The financial benefit that a small-scale CHP system yields will most likely stimulate company investment in such systems. Additional benefits, such as the provision of a standby capability may also be important. In the case of outright capital purchase, companies will seek increased profits beyond a short payback period.

To evaluate the simple payback period for a CHP installation, the costs of purchasing, maintaining and running the unit must be apparent, together with the value of the generated heat and power. The latter will depend on the existing plant and tariffs. The pattern of operation (hours run), both daily and throughout the year, are also crucial in determining the cost-effectiveness of the installation. It is important to determine accurately the electrical and heat load profiles as well as the sizing and design of the CHP installation. These factors should all be properly assessed at the feasibility study stage. There are various no-capital cost options open to an organisation contemplating CHP.

4.1 Total Installed Costs

When evaluating costs it is important to compare specifications and allow for any ancillary equipment which might be necessary.

Total installed capital costs will depend on:

- the supplier;
- the size of the CHP unit;
- the level of control required.

It is vital first to consider other no-cost and low-cost energy savings measures and either implement or take account of those that are appropriate. These will affect the demand profiles of the site and consequently the size, and possibly type, of CHP unit required. Only then should CHP be specified.

Installation costs are more a function of unit size and site complexity than of the choice of equipment supplier. Although the actual installation work will differ in detail from site to site, it will always involve connections with the existing fuel supply, with the heating and electricity services within the building and with a separate flue for combustion products. Unless an individual CHP application has exceptionally demanding installation requirements, the installation costs per kWe will fall with increasing unit size, and will generally account for 25 - 30% of the total cost. Overall costs per installed kWe vary with unit size, typically as shown in Fig 12.

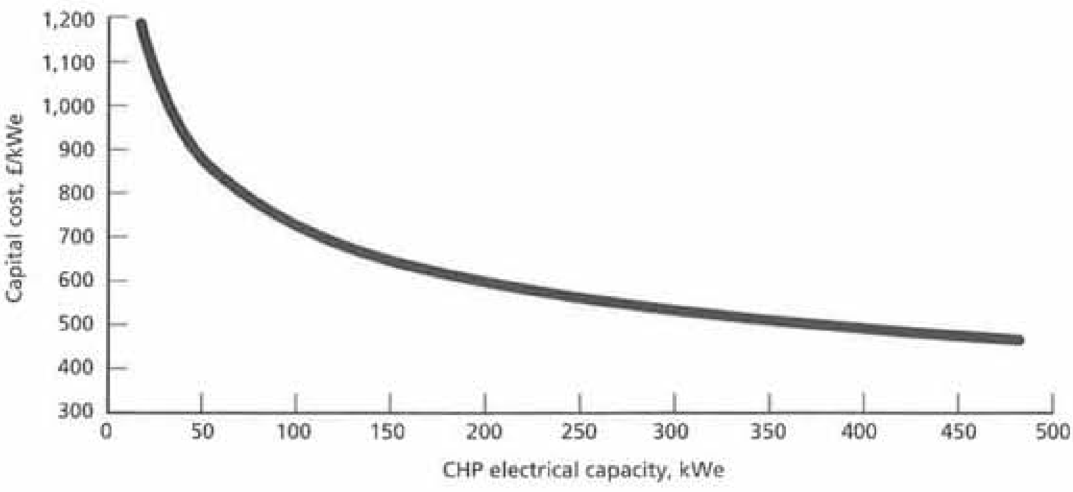

Fig 12 Typical capital and installation costs as a function of electrical capacity

4.2 Financial Arrangements and Contractual Terms

There are several options available when considering the financing of a CHP system. The choice will depend on capital availability and company accounting policy.

Outright capital purchase will yield the greatest long-term return. A very common option, though, is an Equipment Supplier Finance scheme, whereby the CHP company installs and maintains the units free of charge. Under such a scheme, the client pays for the fuel and purchases the generated electricity from the supplier at a reduced price, thus making a net energy cost saving after allowing for the additional fuel used by the CHP unit. In this case, there is no capital outlay and the supplier bears the ongoing maintenance costs and takes nearly all the risk. These finance packages can also cover the CHP system cost only with, for example, installation paid for by the site, thereby providing a higher level of savings or a reduced contract term. Leasing-based financial packages are also available in the form of an agreement with a Contract Energy Management company.

Contract arrangements for CHP should follow the organisation's standard practice, but with the inclusion of guarantees on performance, reliability and costs associated with maintenance requirements. With capital purchase, the user and supplier should negotiate the terms of payment, which could include a performance clause and a maintenance contract.

When purchasing a system, the price should include the cost of tests and full commissioning as well as the supply of operating manuals, drawings and associated documentation.

4.3 Other Costs

When assessing costs and obtaining quotations from equipment manufacturers, it is essential to consider any other costs that might arise. This may include charges by the REC, either for additional protection equipment or for metering changes. Exceptional local conditions may require network reinforcement or special additional protection, but this will usually only apply in rural areas, for larger CHP units, or for multiple-unit installations. The feasibility study should, at an early stage, include discussions with the REC on potential schemes.

The installation of a CHP unit will not normally have a great effect on the overall gas requirements of the site. However, before assuming that no additional charges will be levied, the gas supplier should verify that the existing supply capacity will accept the CHP load.

Installation costs can also be greater than expected since quotations sometimes exclude construction work. There may also be additional charges for the off-loading, cranage and positioning of equipment.

4.4 Cost Savings

Savings from a CHP system are calculated from the difference in the purchased electricity cost compared with the sum of the maintenance costs and the additional CHP fuel costs due to the lower heat production efficiency of CHP units compared with boiler plant. Typically there is a notional 'profit' of around 3.5p for each kWh generated, based on uniform day rate electricity costs. With Maximum Demand (MD) tariffs, additional maximum demand savings will only be achieved with operation of the unit throughout the peak demand periods.

RECs increasingly favour seasonal time of day (STOD) and day/night tariffs. In most circumstances these are beneficial to CHP operation since there are no MD costs and the unit cost itself reflects the peak electricity demand periods.

Savings from a system financed by the CHP supplier are generally based on an agreed cost for each kWh of electricity generated by the system. This is usually indexed to RPI or a similar agreed parameter.

4.5 Maintenance Costs

Careful assessment and consideration of maintenance costs are essential when calculating savings, as they can amount to 30% or more of the gross cost savings from CHP operation.

It is essential to make proper comparisons. To facilitate this, it is important to establish careful life-cycle maintenance costs with the CHP manufacturer. These should include routine service and lubrication costs as well as top end and complete overhaul costs, all on an annual basis.

CHP units generally incorporate microprocessor technology to control and continually monitor the performance and condition of the CHP unit. The logged data can help locate faults and schedule maintenance. In this way high CHP system availability can be achieved with optimised maintenance costs.

Maintenance is usually contracted out, often to the equipment supplier, on an annual or hours-run basis. The actual level of maintenance support can vary between suppliers, and a precise definition of what each particular quoted rate includes is essential. The variation in maintenance costs per kWe installed also depends on the unit type and size. Typical planned maintenance requirements include oil, filter, spark plug and vee-belt changes at intervals of between 600 and 2,000 hours. Such 'routine' maintenance is optional in that a CHP operator may decide to use in-house maintenance staff. External maintenance quotations will normally include all engine parts, including eventual engine overhaul or replacement (if applicable) at some stated number of hours. However, rates may not cover all auxiliary items such as the heat exchangers and other passive parts. Some quoted rates do not include the travel expenses associated with emergency call-out, even if the latter is part of the agreed rate.

Overall maintenance costs vary depending on the size of the unit and range typically from 0.5 to 1.4 p/kWh (Fig 13). Contracts will generally have costs indexed on an agreed annual basis.

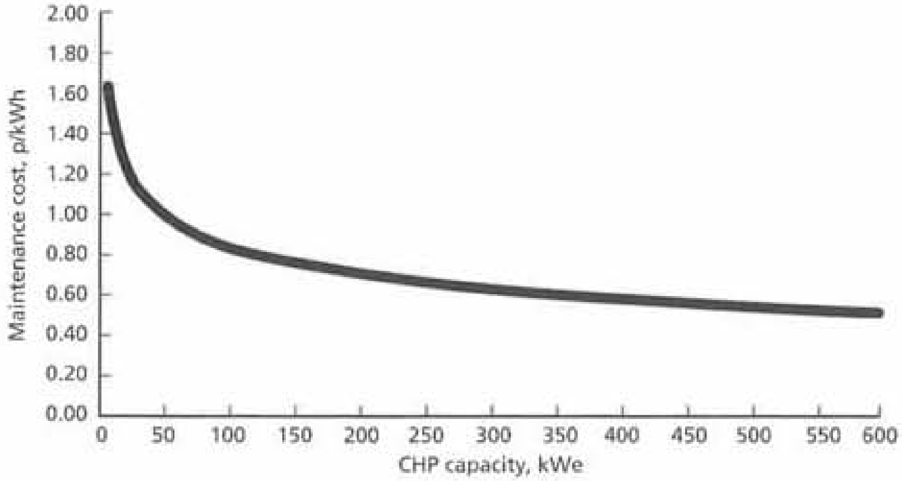

Fig 13 Typical small-scale CHP maintenance costs versus unit size

4.6 Export of Electricity

Regional Electricity Companies may consider buying surplus electricity from a private generator, though the prices normally offered just cover the running costs (fuel, operation and maintenance) of the CHP and are thus not very attractive. In practice, few establishments considering small-scale CHP will have surplus electricity available for export when premium prices are obtainable. It is therefore unlikely that the export of surplus electricity will be a significant consideration in the evaluation of CHP units below 250 kWe. An organisation may find it appropriate to provide additional sites under its control with electricity from the CHP by using the REC system. This will incur Use of System charges which typically range from 0.6 to 1.0 p/kWh. There may also be additional administration charges.

4.7 Standby Generation

Some units can operate independently of the mains supply and, therefore, serve as an emergency power generation facility. However, to justify the investment cost, most units installed for this purpose will be sized for near-base load duty, thereby limiting the usefulness of the plant to providing essential services only.

If such a standby facility is to be provided, additional switchgear will be necessary to isolate both the mains supply and non-essential circuits, which will avoid overloading the plant. Full standby facilities necessitate the installation of larger capacity plant, which will in turn increase the capital costs and lengthen the payback period. In such circumstances, there will have to be a compromise between the acceptable payback criterion and the 'value' of the standby generation facility. Suppliers will often limit the maximum loading in isolation mode to 75% of the rated output in parallel operation to protect the generating set.

The installation of CHP instead of a conventional standby generation facility can offer tangible benefits where the return on investment would otherwise be nil. The experience of engine manufacturers also indicates that regular usage results in improved reliability; many problems arise when engines of standby plant are restarted after long periods of idleness.

4.8 Payback Period

For any particular installation, economic operation depends on availability, reliability and load factor.

Availability means that the plant must be able to operate when necessary. Maintenance during non-premium running periods, along with rectifying failures promptly, will maximise availability. Manufacturers should guarantee the availability level of CHP plant.

Regular and effective maintenance determines reliability, not only of the CHP unit but also of its associated plant and controls.

High load factors depend both on availability and reliability, and on careful system matching and control optimisation. This ensures that the plant operates whenever it is profitable to do so.

If not properly used, a CHP system selected to give a payback period of approximately 3 years can easily slip to 4 years or more. However, with careful sizing and sensible usage, a payback of 3 to 5 years is achievable, depending upon the size of the unit and the annual hours of operation.

5. IMPLEMENTATION AND SUCCESSFUL OPERATION OF SMALL-SCALE CHP

The design of a system incorporating small-scale CHP differs in several ways from the approach using a conventional boiler. A feasibility study should occur at an early stage to assess the heating loads and electricity demand in order to size and design the CHP installation accurately. Detailed life-cycle costs should be firmly established at the contract stage and contracts should also include performance guarantees. The most suitable maintenance contract will depend on site factors and resources but can range from fully inclusive to annual inspection servicing.

The RECs are primarily concerned with the safety of new installations, and discussions should ascertain the requirements. The gas supplier should also assess the supply and metering implications of the proposed CHP installation.

5.1 Guidelines to the Successful Operation of Small-scale CHP

The Building Services controls for a CHP system should be designed to ensure that the system operates as the 'lead boiler', in preference to the auxiliary heating boilers, and for the maximum number of hours each day. While the heating requirement mainly determines usage, this is easier to achieve in situations where the CHP output represents only a small proportion of the total load.

Control systems will not operate satisfactorily if sensors are not positioned properly. One way of ensuring accurate sensing is through appropriate pipework design, including the use of large headers to allow thorough mixing of water temperatures within the system.

As well as the implementation of an effective CHP and boiler plant control system, it is essential to establish an operating strategy to ensure the optimum running of the CHP system. A particularly effective control strategy for CHP systems is based on regulating the return header temperature. Once satisfactory operation of the entire plant has been achieved, day-to-day operational requirements should be relatively minor.

In common with other reciprocating engine plant, CHP units can produce high levels of carbon monoxide (CO) if not correctly adjusted. Particular attention should therefore be paid to exhaust system integrity as well as flue gas dispersion when the plant room is adjacent to other occupied buildings. There must also be adequate ventilation in the plant room to provide enough combustion air.

While the engines in small-scale CHP units are usually acoustically enclosed, it is possible to experience noise levels of approximately 65 - 75 dBA at 1 metre. Where these noise levels may be a problem, additional soundproofing should be considered. Flue outlets and air inlets should be located to minimise noise levels, particularly if the equipment is near residential areas and is likely to operate at night.

The fully automated microprocessor-controlled CHP units now available need no intervention by site personnel and restart automatically in case of temporary failure. Temporary loss of CHP plant should not affect the overall services, since auxiliary heating and mains electricity supply should always be available.

Savings can be calculated through regular monitoring of the CHP unit by metering gas consumption, electrical and heat output as well as operational hours. Most manufacturers provide regular performance reports covering these parameters and highlighting any operational difficulties and actions to rectify the situation.

The various design stages can be summarised as:

- setting aside time for discussions with the REC and gas supplier;
- ensuring proper pipework and control system design;
- ensuring the control strategy operates CHP preferentially;
- placing flue outlets away from residential accommodation.

The important maintenance and operation considerations are:

- allowing for changing Building Services control procedures after a suitable period of operation;
- ensuring a full maintenance service that has been properly costed.

6. THE WAY FORWARD

There are many potential applications for small-scale CHP, but it is not always easy to decide whether or not a particular site will be both technically sound and cost-effective. An important factor in sizing CHP systems is the heat demand of the building and/or its services. To achieve a simple payback period of 3 - 5 years, a CHP unit generally must typically operate for more than 4,500 hours/year.

To assess the suitability of a site for CHP it is necessary to check a number of separate factors. This should be take place in stages, as the final decision will involve obtaining detailed information. Unless the initial findings are encouraging, the effort entailed may not be worthwhile. The following procedure provides a simple and logical method of assessing the viability of a particular installation:

- carry out a basic assessment using site data and a check-list as detailed in Good Practice Guide 1 (GPG 1);
- carry out a detailed assessment (see GPG 1), or find a competent energy consultant[1] who can do it for you;
- contact appropriate equipment suppliers (Appendix 1) to discuss your installation and obtain a quotation from more than one supplier if possible;
- try to visit an installation at a site similar to your own with the equipment supplier and your consultant;
- contact your REC and gas supplier and, with the equipment supplier and consultant, discuss the tariff and supply implications of your proposed project;
- decide on the proposal in terms of payback, reliability and other factors outlined in this booklet.

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1 Advice on the selection of a competent consultant can be obtained from:

Association of Consulting Engineers
12 Caxton Place
London
SW1H 0QL
Tel: 0171 222 6557

Energy Systems Trade Association
P.O. Box 16
Stroud
Gloucestershire GL5 5EB
Tel: 01453 873568

Chartered Institution of Building Services Engineers
Delta House, 222 Balham High Road
London
SW12 9BS
Tel: 0181 675 5211

Institute of Energy
18 Devonshire Street
Portland Place
London
W1N 2AU
Tel: 0171 580 7124

The Combined Heat and Power Association
Grosvenor Gardens House
35-37 Grosvenor Gardens
London
SW1W 0BS
Tel: 0171 828 4077

See also the booklet 'Choosing An Energy Efficiency Consultant', available from your Regional Energy Efficiency Office or from ETSU.

APPENDIX 1

CURRENT LIST OF SMALL-SCALE CHP EQUIPMENT SUPPLIERS

The following list of equipment suppliers will assist potential users. The list is not exhaustive and has been compiled from data currently available to ETSU. The listing of an organisation does not constitute an endorsement by the DOE of its competence, and the non-listing of an organisation does not discriminate against its competence.

AVK/SEG (UK) Ltd
Unit 9, Ministry Wharf
Saunderton
High Wycombe
Buckinghamshire
HP14 4HW
Tel: 01494 564541

Base Load Systems
Acorn House
Victoria Road
London
W3 6UL
Tel: 0181 896 0384

Biddle Air Systems Ltd
St Mary's Road
Nuneaton
Warwickshire
CV11 5AU
Tel: 01203 384233

Broadcrown Ltd
Alliance Works
Stone
Staffordshire
ST15 8BA
Tel: 01785 817513

Countryman Cogen Systems Ltd
6 -10 Crompton Way
Crawley
West Sussex
RH10 2QR
Tel: 01293 526456

Combined Energy Systems
1st Floor Wing F
Carlyle House
Carlyle Road
Kirkcaldy
KY1 1DB
Tel: 01592 644080

Combined Power Systems Ltd.
Trafford Wharf Road
Manchester
M17 1GQ
Tel: 0161 873 8363

Dale Power Systems Ltd
Electricity Buildings
Filey
North Yorkshire
YO14 9PJ
Tel: 01723 514141

Energen Technology
36 Charter Gate
Quarry Park Close
Moulton Park
Northampton
NN3 6QB
Tel: 01604 499975

Enviropower Ltd
Unit 6A
Lodge Way
Severn Bridge Industrial Estate
Caldicot
Gwent
NP6 4TH
Tel: 01291 421411

George Mellor Ltd
Orion Park
Northfield Avenue
Ealing
London
W13 9SJ
Tel: 0181 579 2111

H. Leverton Ltd
Maidenhead Road
Windsor
Berkshire
SL4 5HH
Tel: 01753 845499

Hedemora Diesel Ltd
4 Henson Close
Telford Way Industrial Estate
Kettering
Northamptonshire
NN16 8PZ
Tel: 01536 415575

Lincoln Green Energy
PO Box 214
Wilford Road
Nottingham
NG2 1EA
Tel: 0115 986 7000

Machine Manpower Management
15 Unity Grove
Knowsley Industrial Park South
Knowsley
Liverpool
L34 9GT
Tel: 0151 546 4446

Nedalo (U. K.) Ltd.
Lawson Hunt Industrial Park
Broadbridge Heath
Horsham
W. Sussex
RH12 3JR
Tel: 01403 272270

Petbow Cogeneration Ltd
Botanical House
Botanical Avenue
Talbot Road
Old Trafford
Manchester
M16 0PQ
Tel: 0161 877 3210

PUMA Power Plant
37 Sandwich Road
Ash
Canterbury
Kent
CT3 2AJ
Tel: 01304 812818

Swan Generators Limited
Overthorpe Road
Banbury
Oxfordshire
OX16 8SX
Tel: 01295 261601

Zantingh (UK) Ltd
Nordic House
Lansdown
Cheltenham
Gloucestershire
GL50 2JZ
Tel: 01242 242313